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Effective Use of Cost Risk Reports

7 – 10 June 2011

Alfred Smith CCEA

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Outline

- **Typical steps in an uncertainty analysis**
- **Model Overview**
  - WBS, methods, variables, uncertainty
  - Statistical Risk Reports
    - Statistics, Correlation, Allocation
- **Cost Risk Reports**
  - Pareto, Tornado, Variance Analysis (also called “sensitivity”)
  - Exploit these charts to find cost and variance drivers
  - Relationship to risk allocation results (used to propose a budget)
- **Summary**

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Defining Cost Risk Reports

- **Different opinions on what a cost driver is:**
  - The WBS element that contributes the most to the total
  - The variable (labor rate, weight, etc) that has the most influence on total cost
- **SCEA's "Body of Knowledge" defines:**
  - **Cost Passenger**: WBS elements with the highest dollar value
  - **Cost Driver**: those design decisions and requirements, especially at a system level, that truly drive or influence cost
  - By extension, we can use the same definitions to describe a variance passenger (WBS element) and variance driver (input)
- **Cost Risk Reports are those that help you identify your cost risk drivers**

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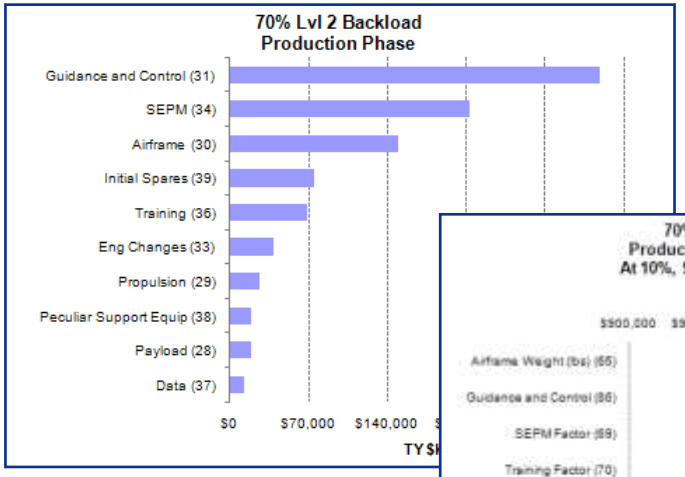
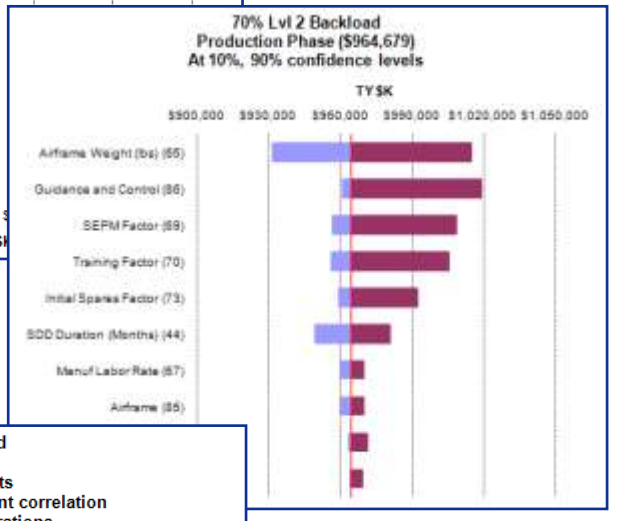
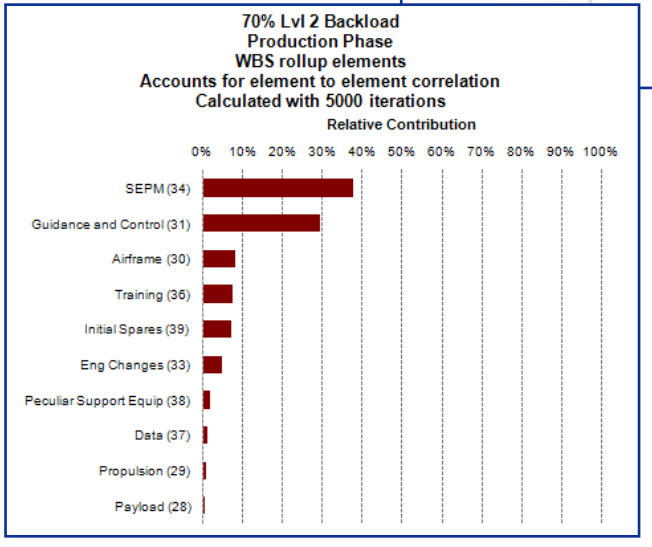
Find the Cost and Uncertainty Drivers

- **Pareto Chart:** identifies WBS elements that contribute most to the target row *total*
- **Tornado/Spider Chart:** identifies the uncertain variables that most influence the target row *total*
- **Variance Analysis (Rollup):** identifies *WBS elements* that contribute most to the target row *uncertainty*
- **Variance Analysis (Driver- not shown** but similar in appearance to RollUp**):** identifies the defined distributions that contribute most to the target row *uncertainty*







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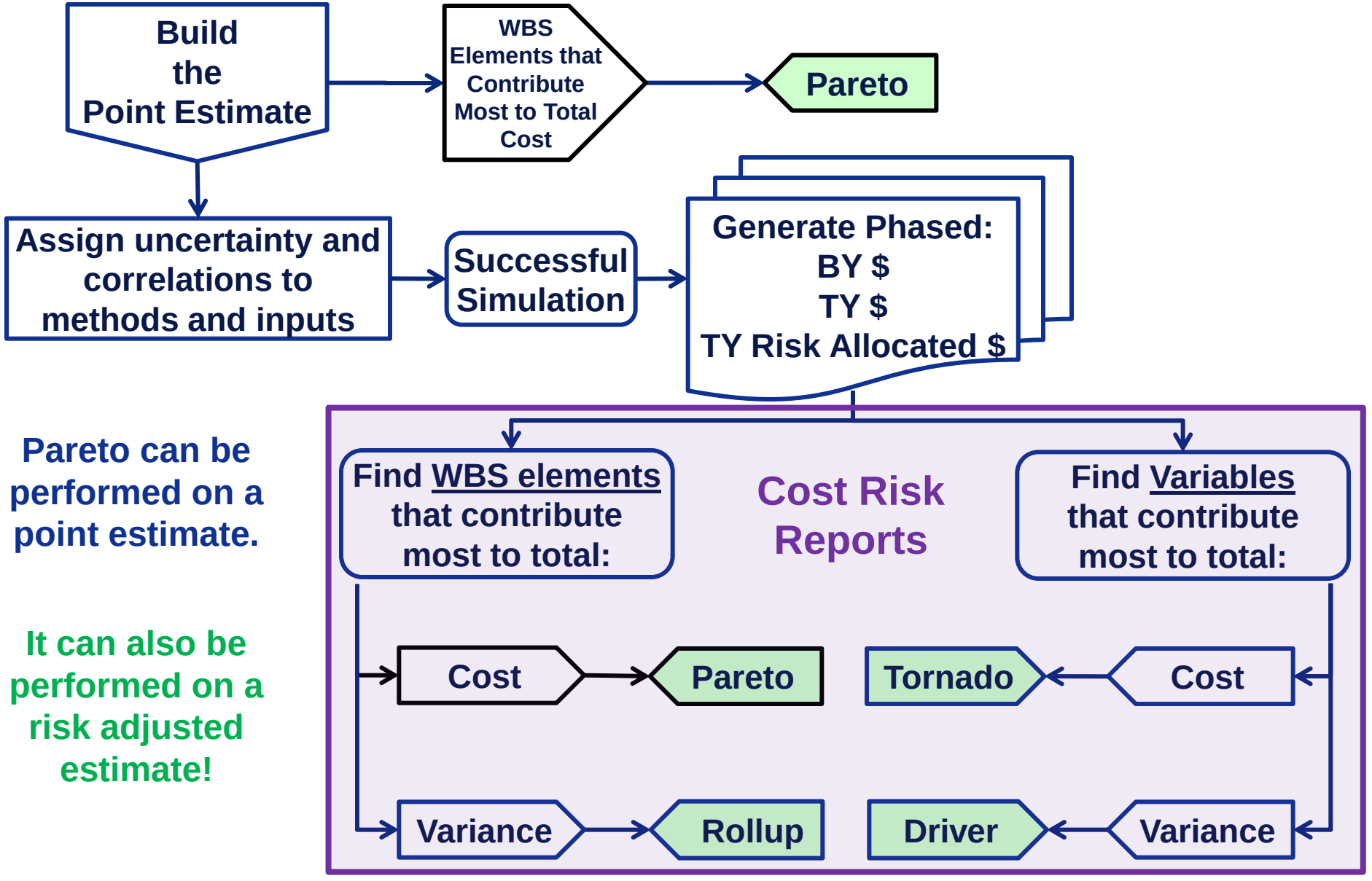
The Path To Various Reports



Pareto can be performed on a point estimate.

It can also be performed on a risk adjusted estimate!

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Find the Cost and Uncertainty Contributors

- **We have the tools to find the key cost and uncertainty drivers**
- **But, is the search influenced by**
  - type of dollars reported (ie. BY vs TY)?
  - risk allocation choices we make?
    - WBS level we choose to allocate from
    - confidence level
- **Are the considerations different for each cost risk report?**
- **Even if we settle on the "best" way to perform the search, is it possible? Is it feasible?**
- **Let's embark on a search**

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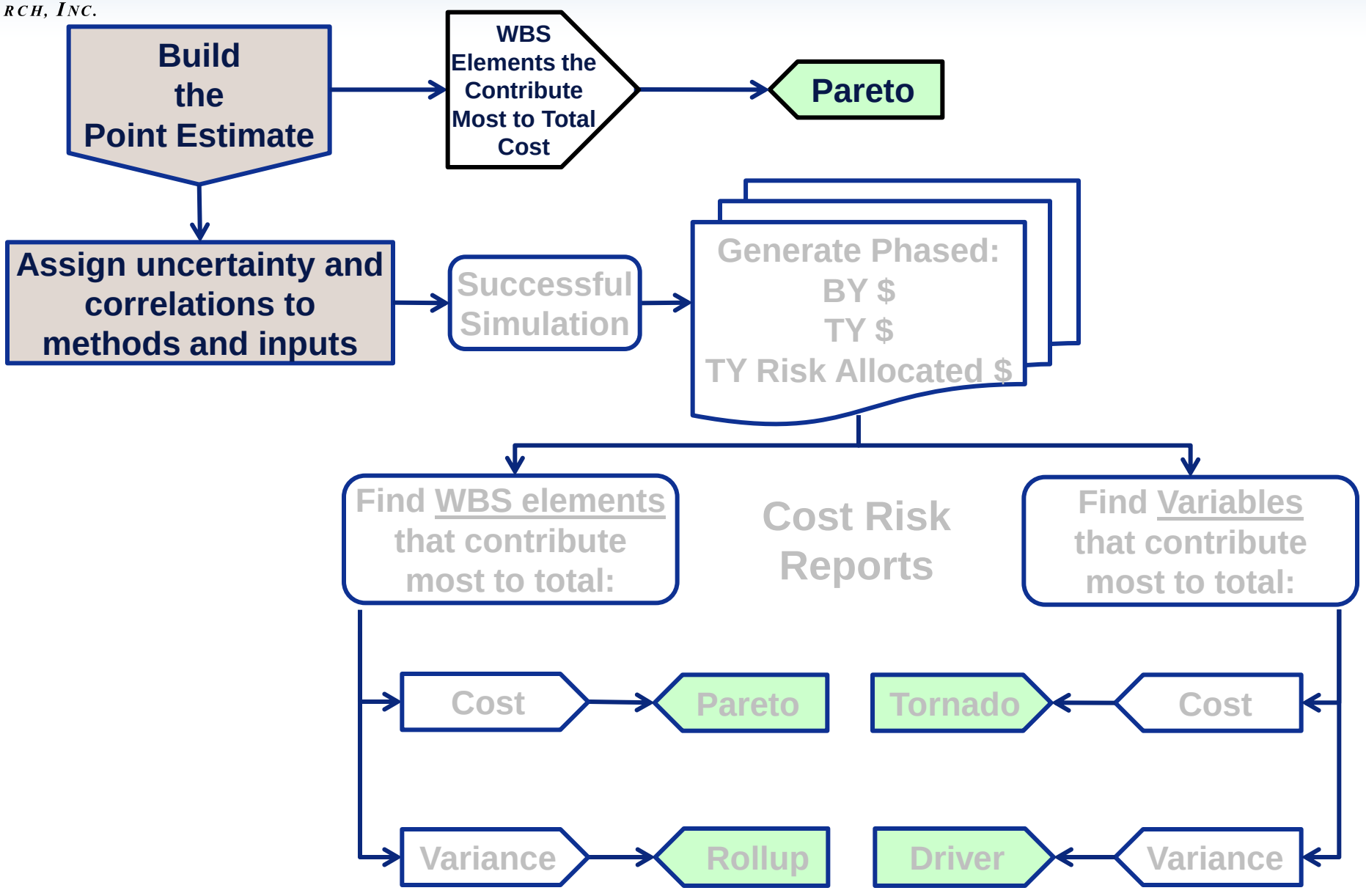
Create the Risk Model



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AFCAA CRUH Missile Model

WBS

- Missile System
  - Sys Dev and Demo
    - Air Vehicle
      - Design & Dev
      - Prototypes
      - Software
    - SEPM
    - Sys Test & Eval
    - Training
    - Data
    - Support Equip
  - Production Phase
    - Air Vehicle
      - Payload
      - Propulsion
      - Airframe
      - Guidance and Control
      - IAT&C
    - Eng Changes
    - SEPM
    - Sys Test & Eval
    - Training
    - Data
    - Peculiar Support Equip
    - Initial Spares

Target for analysis in this presentation

Inputs

- DEVELOPMENT VARIABLES
  - Start Sys Dev and Demo (SDD)
  - SDD Duration (Months)
  - End of SDD
  - Protoype Quantity
  - Development Learning Slope
  - Step Increase over Prod Cost
  - SW Manmonths
  - SW Labor Rate ($/month)
  - SEPM Headcount
  - SEPM Labor Rate ($/mo)
  - Sys Test Eval Factor
  - Training Factor
  - Data Factor
  - Support Equip Factor
- PRODUCTION VARIABLES
  - Production Start Date
  - Production Quantity
  - Production Stop Date
  - Production Learning Slope
  - Warhead Weight (lbs)
  - Motor Weight (lbs)
  - Airframe Weight (lbs)
  - IATC Hrs/Unit
  - Manuf Labor Rate
  - Eng Changes Factor
  - SEPM Factor
  - Training Factor
  - Data Factor
  - PSE Factor
  - Initial Spares Factor

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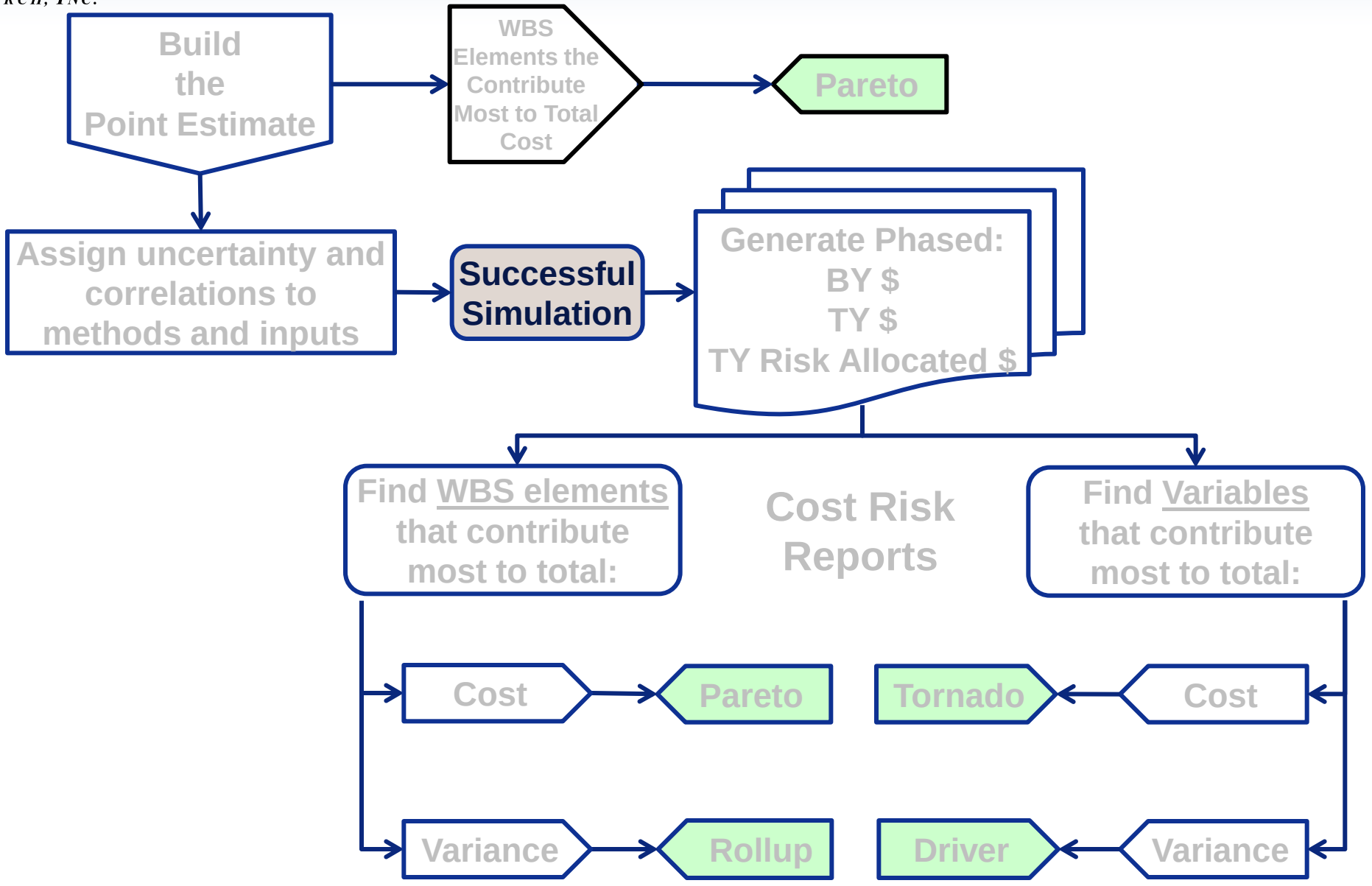
Successful Simulation



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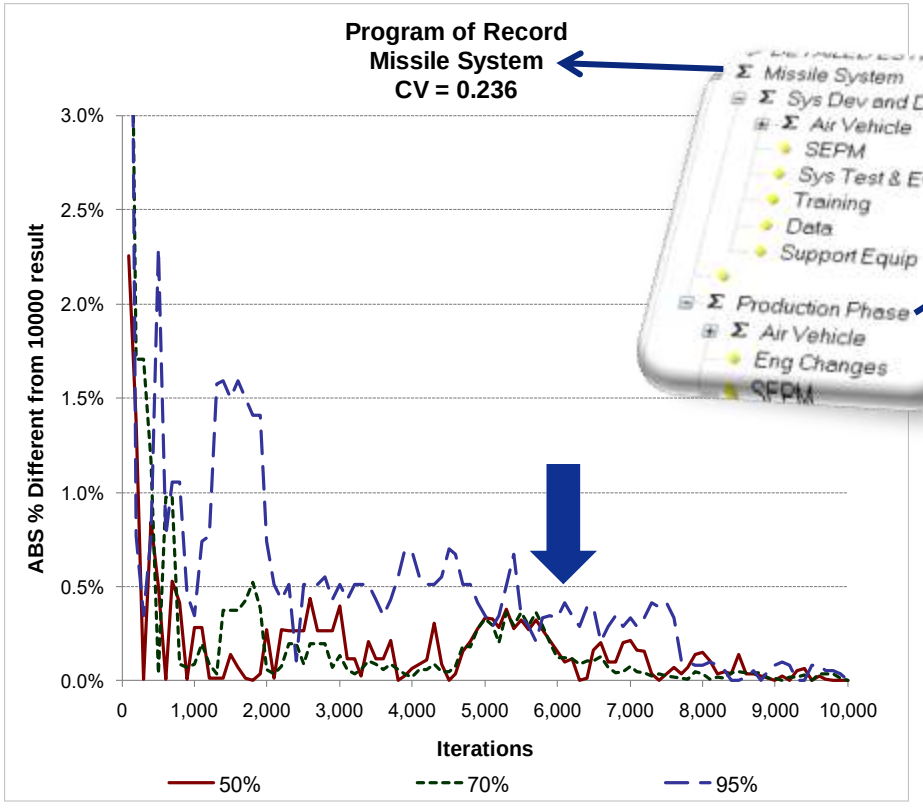
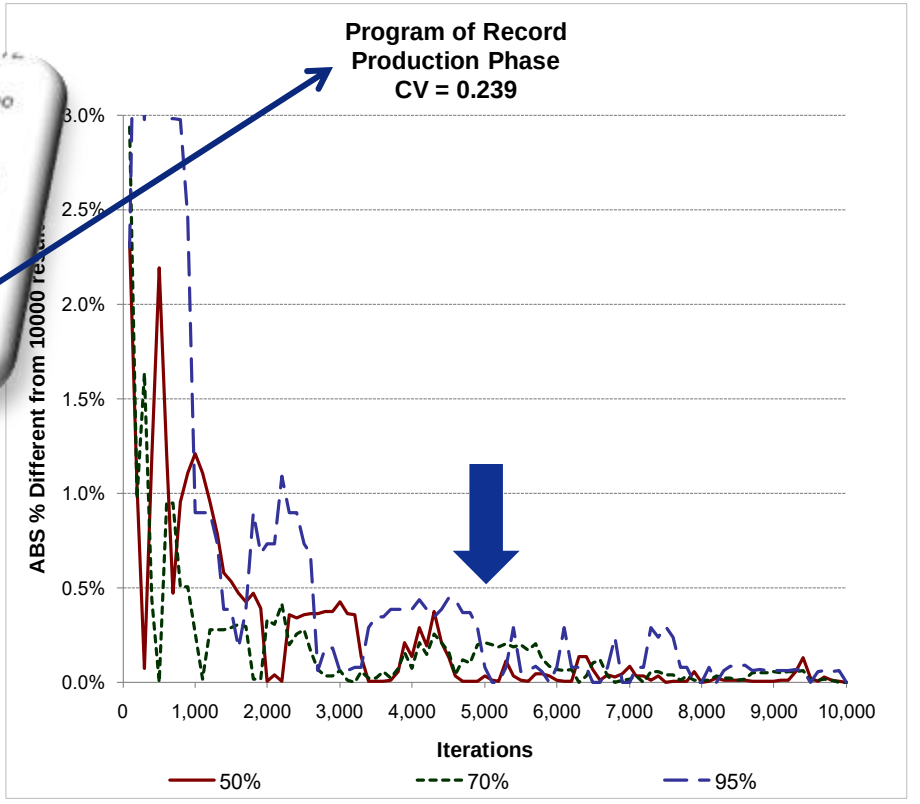
Once Model is Complete, Determine Iterations Required





- **A Convergence Chart will yield a different result depending on the target!**
- **5,000 iterations appears to be adequate[1] to evaluate the Production Phase**
  - If convergence is not achieved, need to re-run the analysis using > 10k iterations (see backup slide)
- **Must reassess if model changes**

[1]How Many Iterations Are Enough?, Alfred Smith, Tecolote Research, Joint SCEA/ISPA Annual Conference, June 2008

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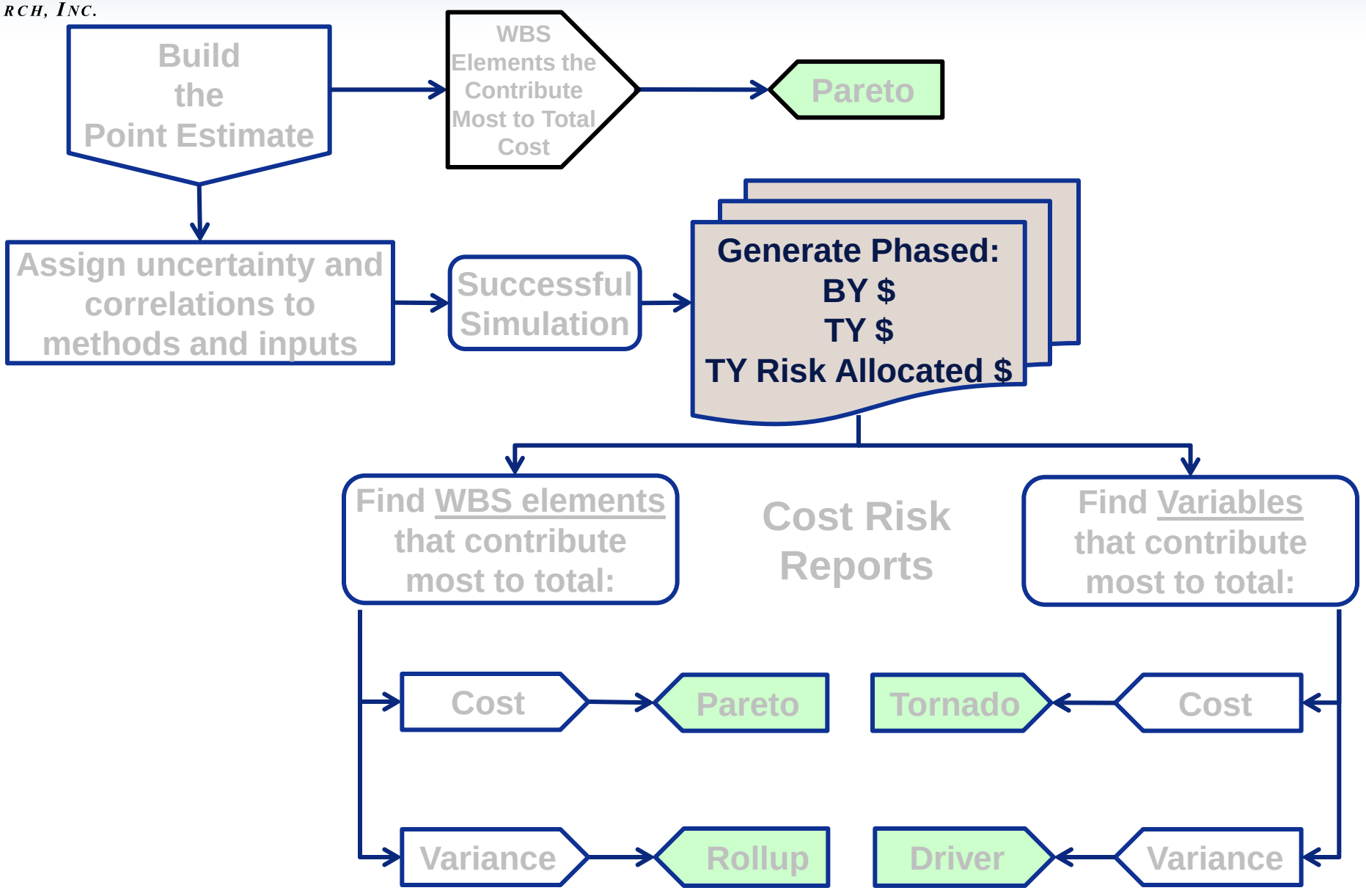
Generate Reports



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Risk Statistics Reports

Risk Statistics

- Particularly interested in CV at this point

	WBS/CES	Point Estimate	Mean	Std Dev	CV	5.0% Level	10.0% Level	15.0% Level	20.0 Leve
14	Missile System	$ 718,557 (13%)	$ 979,884	$ 243,945	0.249	$ 640,927	$ 690,594	$ 731,888	$ 767
15	Sys Dev and Demo	$ 170,002 (27%)	$ 226,409	$ 84,160	0.372	$ 125,405	$ 139,752	$ 150,444	$ 158
16	Air Vehicle	$ 115,178 (32%)	$ 147,406	$ 56,890	0.386	$ 79,525	$ 89,349	$ 96,010	$ 102
17	Design & Dev	$ 26,506 (25%)	$ 31,920	$ 6,901	0.216	$ 22,019	$ 23,523	$ 24,676	$ 25
18	Prototypes	$ 10,328 (20%)	$ 15,942	$ 6,323	0.397	$ 7,321	$ 8,621	$ 9,504	$ 10
19	Software	$ 78,344 (40%)	$ 99,545	$ 52,443	0.527	$ 39,324	$ 47,294	$ 52,849	$ 58

Correlation Report

- **Measure** what is present and adjust as required

Production →

	WBS/CES	Row 28: Payload	Row 29: Propulsion	Row 30: Airframe	Row 31: Guidance and Control	Row 32: IAT&C	Row 33: Eng Changes	Row 34: SEPM
28	Payload	1.00	0.32	0.33	0.24	0.43	0.30	0.26
29	Propulsion		1.00	0.26	0.19	0.23	0.29	0.26
30	Airframe			1.00	0.19	0.26	0.40	0.36
31	Guidance and Co				1.00	0.13	0.57	0.50
32	IAT&C					1.00	0.20	0.19
33	Eng Changes						1.00	0.47
34	SEPM							1.00

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Phased Risk Allocation Report

- **Why do we produce a phased risk allocation report?**
  - Statistics reports are on the totals, not annual
  - Specific confidence level results do not sum
- **Risk allocation reports tabulate phased risk results at a user selected confidence level, and force the annual results to sum**
  - Example below illustrates results when user selects 70% at the 2nd level in the WBS

	Cost Element	Approp	Total	FY 2010	FY 2011	FY 2012	FY 2013	FY 201
2	Total		$ 620,849 (~71%)	$ 1,299	$ 1,860	$ 6,788	$ 13,594	$ 23,
3	RDT&E		$ 90,382 (70%)	$ 1,299	$ 1,860	$ 6,788	$ 13,594	$ 23,
4	Concept Refinement		$ 1,318 (69%)	$ 1,296	$ 22			
5	Technology Development		$ 5,529 (70%)		$ 1,835	$ 3,694		
6	System Development and D		$ 83,535 (69%)	$ 3	$ 3	$ 3,094	$ 13,594	$ 23,
7								
8	Procurement		$ 530,466 (70%)					
9	Manufacturing (Air Force)		$ 240,742 (68%)					

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Compare Phased Results

ACE 7.1a - [AUCHowToRiskExample12Jan09.aceit - BY Phased Costs (FY2009 $K, Time Phased, Case: Point Estimate, with Risk)]

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Point Estimate

PE

$531k

	Cost Element	Approp	Total	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2018	FY
15	Total		$ 530,935 (30%)	$ 1,005	$ 1,437	$ 5,217	$ 10,124	$ 16,860	$ 25,319	$ 25,937	$ 22,003	$ 22,464	$
16	RDT&E		$ 67,470 (10%)	$ 1,005	$ 1,437	$ 5,217	$ 10,124	$ 16,860	$ 25,319	$ 7,509			
17	Concept Refinement		$ 1,020 (14%)	$ 1,003	$ 17								
18	Technology Development		$ 4,270 (15%)		$ 1,417	$ 2,853							
19	System Development and D		$ 62,180 (11%)	$ 2	$ 2	$ 2,364	$ 10,124	$ 16,860	$ 25,319	$ 7,509			
20													
21	Procurement		$ 463,465 (37%)							$ 18,428	$ 22,003	$ 22,464	$
22	Manufacturing (Air Force)		$ 218,803 (41%)							$ 2,438	$ 5,914	$ 4,129	

ACE 7.1a - [AUCHowToRiskExample12Jan09.aceit - BY Phased (FY2009 $K, Time Phased, Case: Point Estimate, 70% CL allocated at Level 1)]

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70% Allocated from the 1st level

70%, 1st Lvl

$617k

	Cost Element	Approp	Total	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY 2
15	Total		$ 617,04 (70%	$ 1,292	$ 1,850	$ 6,749	$ 13,515	$ 22,978	$ 33,523	$ 31,956	$ 27,649	$ 2
16	RDT&E		$ 89,805 (6	$ 1,292	$ 1,850	$ 6,749	$ 13,515	$ 22,978	$ 33,523	$ 9,898		
17	Concept Refinement		$ 1,311 (68%)	$ 1,289	$ 22							
18	Technology Development		$ 5,499 (68%)		$ 1,825	$ 3,674						
19	System Development and D		$ 82,996 (68%)	$ 3	$ 3	$ 3,076	$ 13,515	$ 22,978	$ 33,523	$ 9,898		
20												
21	Procurement		$ 527,239 (68%)							$ 22,058	$ 27,649	$ 2
22	Manufacturing (Air Force)		$ 239,591 (66%)							$ 2,617	$ 8,103	$ 5

ACE 7.1a - [AUCHowToRiskExample12Jan09.aceit - BY Phased (FY2009 $K, Time Phased, Case: Point Estimate, 70% CL allocated at Level 2)]

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70% Allocated from the 2nd level

70%, 2nd Lvl

$621k

	Cost Element	Approp	Total	FY 2010	FY 2011	FY 2012	FY 2013	FY 2014	FY 2015	FY 2016	FY 2017	FY
2	Total		$ 620,849 (~71%)	$ 1,299	$ 1,860	$ 6,788	$ 13,594	$ 23,123	$ 33,744	$ 32,229	$ 27,888	$
3	RDT&E		$ 90,382 (70%	$ 1,299	$ 1,860	$ 6,788	$ 13,594	$ 23,123	$ 33,744	$ 9,974		
4	Concept Refinement		$ 1,318 (69%)	$ 1,296	$ 22							
5	Technology Development		$ 5,529 (70%)		$ 1,835	$ 3,694						
6	System Development and D		$ 83,535 (69%)	$ 3	$ 3	$ 3,094	$ 13,594	$ 23,123	$ 33,744	$ 9,974		
7												
8	Procurement		$ 530,466 (70%									
9	Manufacturing (Air Force)		$ 240,742 (68%)									

Allocating from further down the WBS causes Total to increase when % is above the mean!

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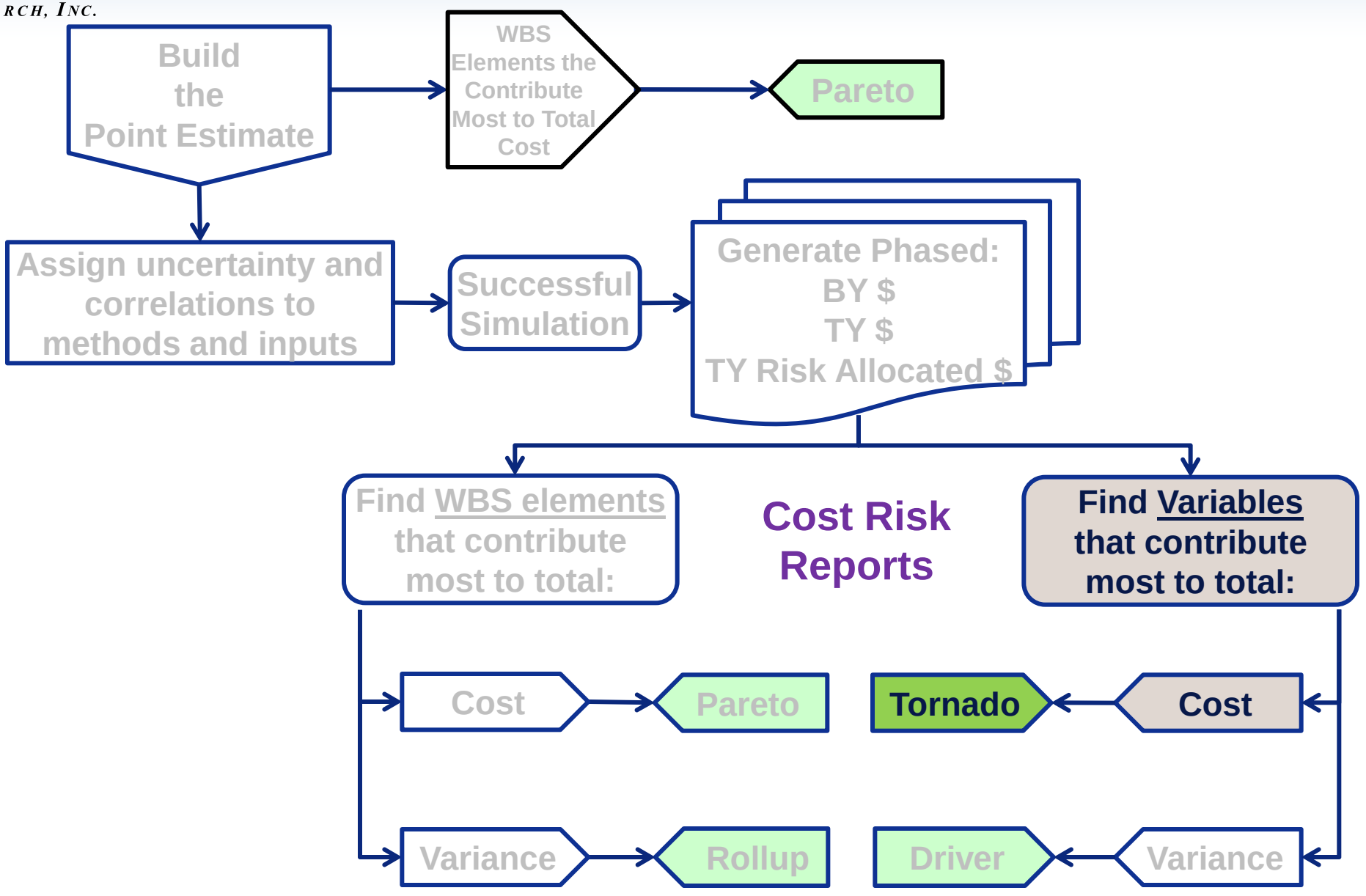
Find the Cost Drivers



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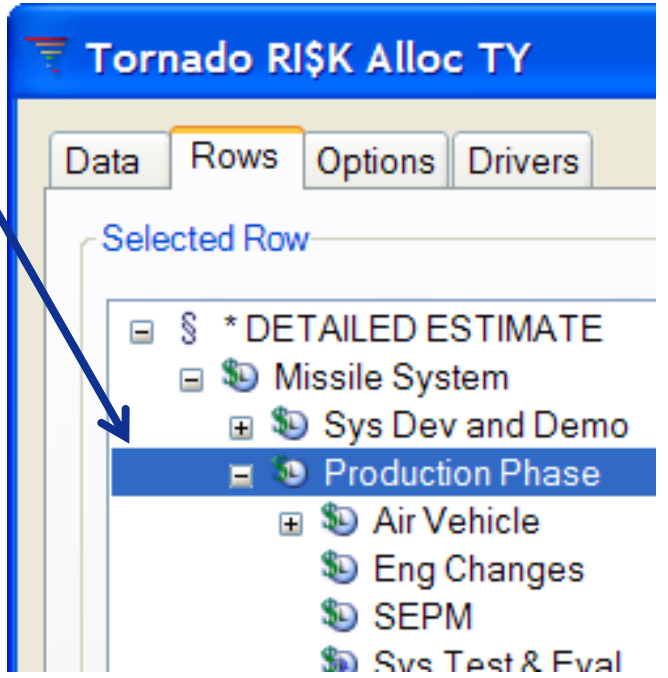
What Does A Tornado Chart Tell You?

- **Select the element to analyze (target row)**
- **Tool identifies all elements that influence the target row result**
  - focus on those elements of interest
- **A low and high what-if is calculated for each driver**
  - 1000 drivers means 2000 what-if cases
- **The Tornado chart plot identifies those drivers that have the most influence on the target row**



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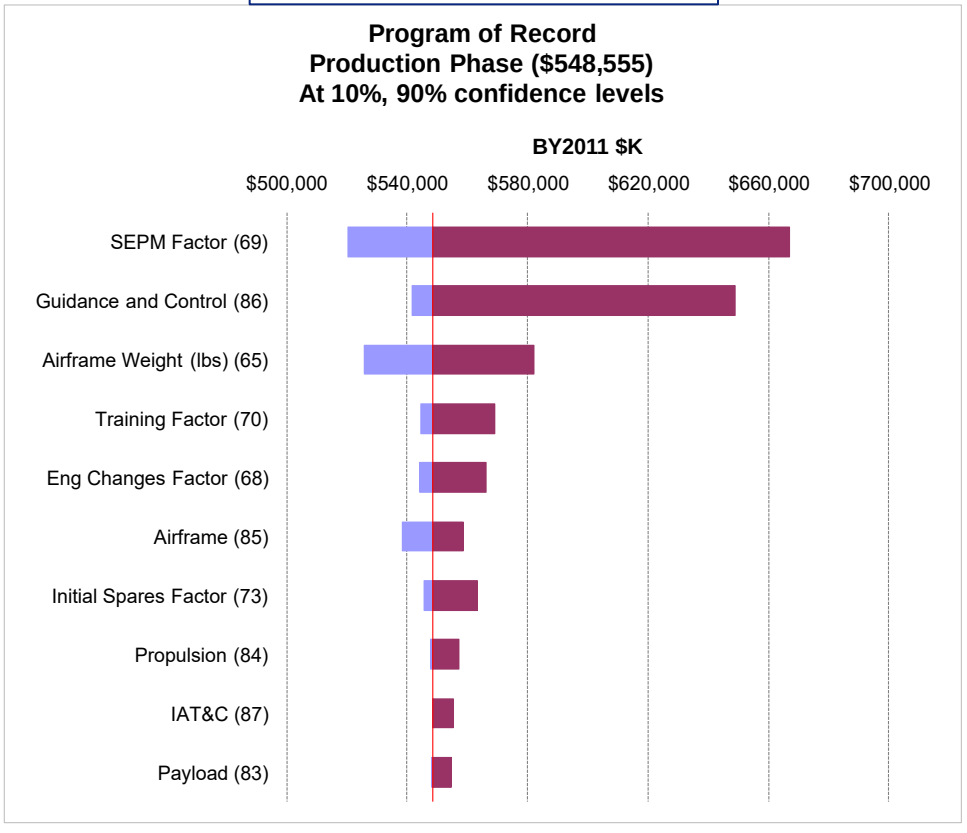
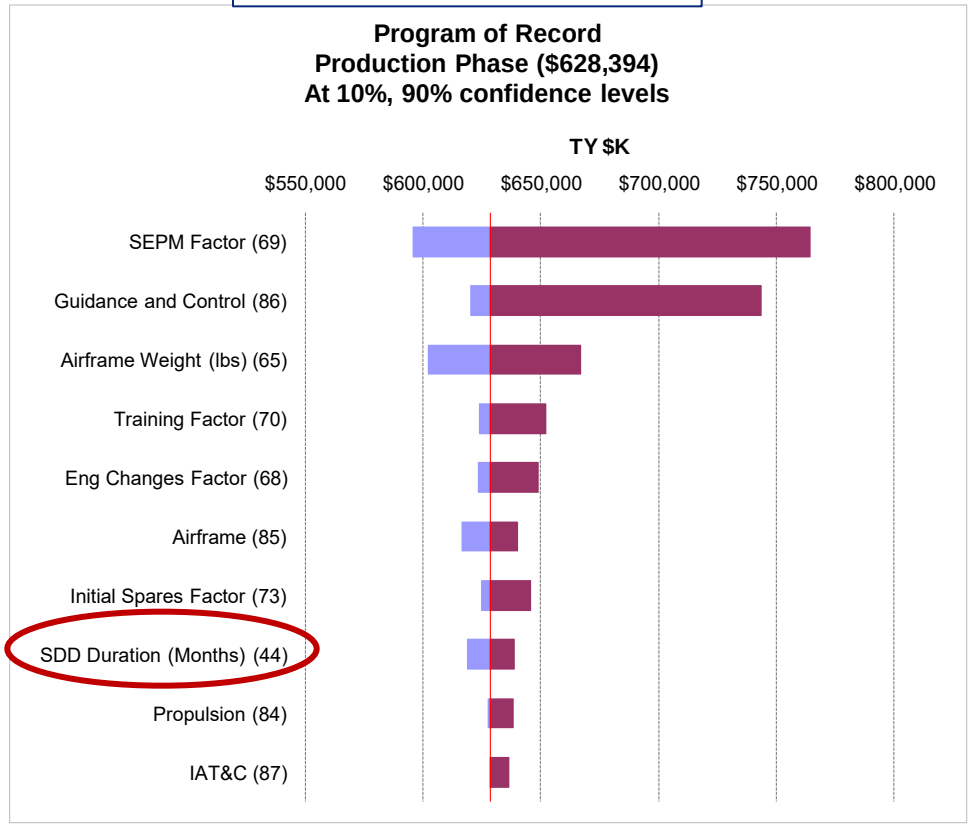
Tornado Based on What? BY vs TY

Not Recommended



Better



- **Tornado based on:**
  - 10/90 bounds of inputs that influence the Production Phase
  - BY dollars - does not account for time phasing of dollars
- **Same Tornado in TY$**
  - A better choice, accounts for phasing
  - SDD Duration does not affect BY$ results, but it does affect TY!

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What about a Tornado based on a Risk Allocated Result?

- **Create a risk allocated result based upon the percentile you plan to use as the basis for your budget**
- **Run the Tornado against the risk allocated results**
- **Process should:**
  - Evaluate a new risk allocated case based for the lower and upper bound of each variable to be examined
  - Remember to evaluate the TY risk allocated result (not BY)
  - The simulation will need to run twice for each variable examined (low and high)

		Target Row Results			Risk Range Inputs		
Drivers (exlcuding Rollup, Zer	Row	Delta	5%	95%	Point Estimate	5%	95%
Airframe Weight (lbs) (65)	65	$106,311	$918,788	$1,025,099	369.7010	231.1232	471.3310
Guidance and Control (86)	86	$69,394	$951,153	$1,020,547	1.20	0.95	1.38
SEPM Factor (69)	69	$62,752	$945,847	$1,008,600	0.421	0.115	0.623

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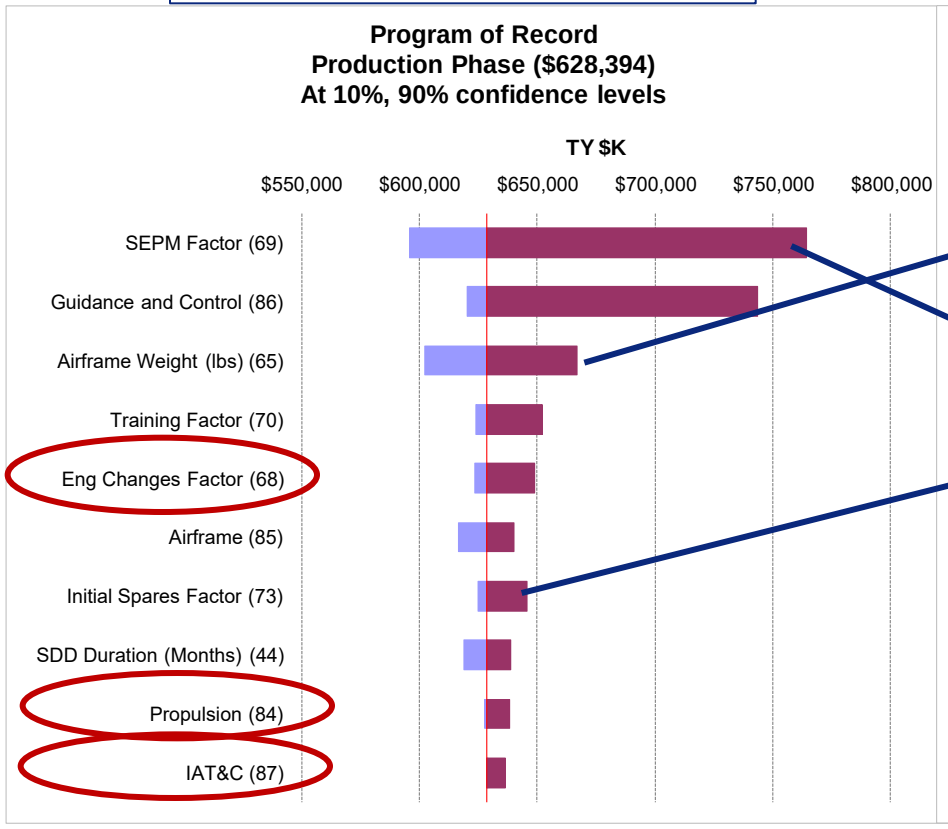
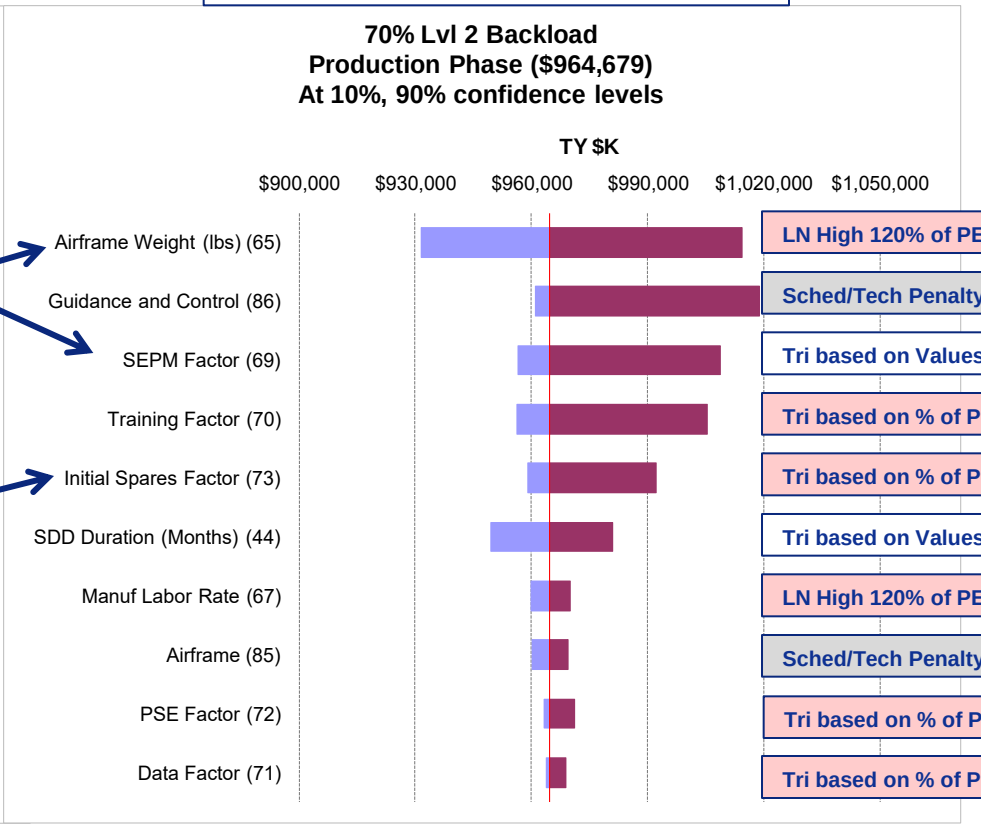
Tornado: TY Point Estimate vs TY Risk Allocated

Not Recommended



Recommended



- **Based on Point Estimate in TY$**
- **Several significant differences when compared to Tornado based upon a risk allocated result**

- **Based on Risk Alloc Case in TY$**
  - 70% conf lvl, allocated from the 2nd level in the WBS, back loaded
  - Review how uncertainty is modeled in the key drivers to verify results are logical

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Tornado Recommendations

- **Run both the Point Estimate TY$ and the Risk Allocated case in TY$**
- **Note the differences to influence your identification of cost drivers**
- **For this model:**
  - Must use TY$ report to ensure methods driven by schedule elements are properly assessed (i.e., SDD duration)
  - Airframe is the top cost driver if we think the uncertainty will scale with the point estimate
  - Our model of Schedule/Technical penalty for Guidance and Control is the second most important regardless of which Tornado is generated (even BY$)
  - 10/90 bounds to define the Tornado analysis is a common standard, but worthy of debate (vs 80/20 or some other combination)

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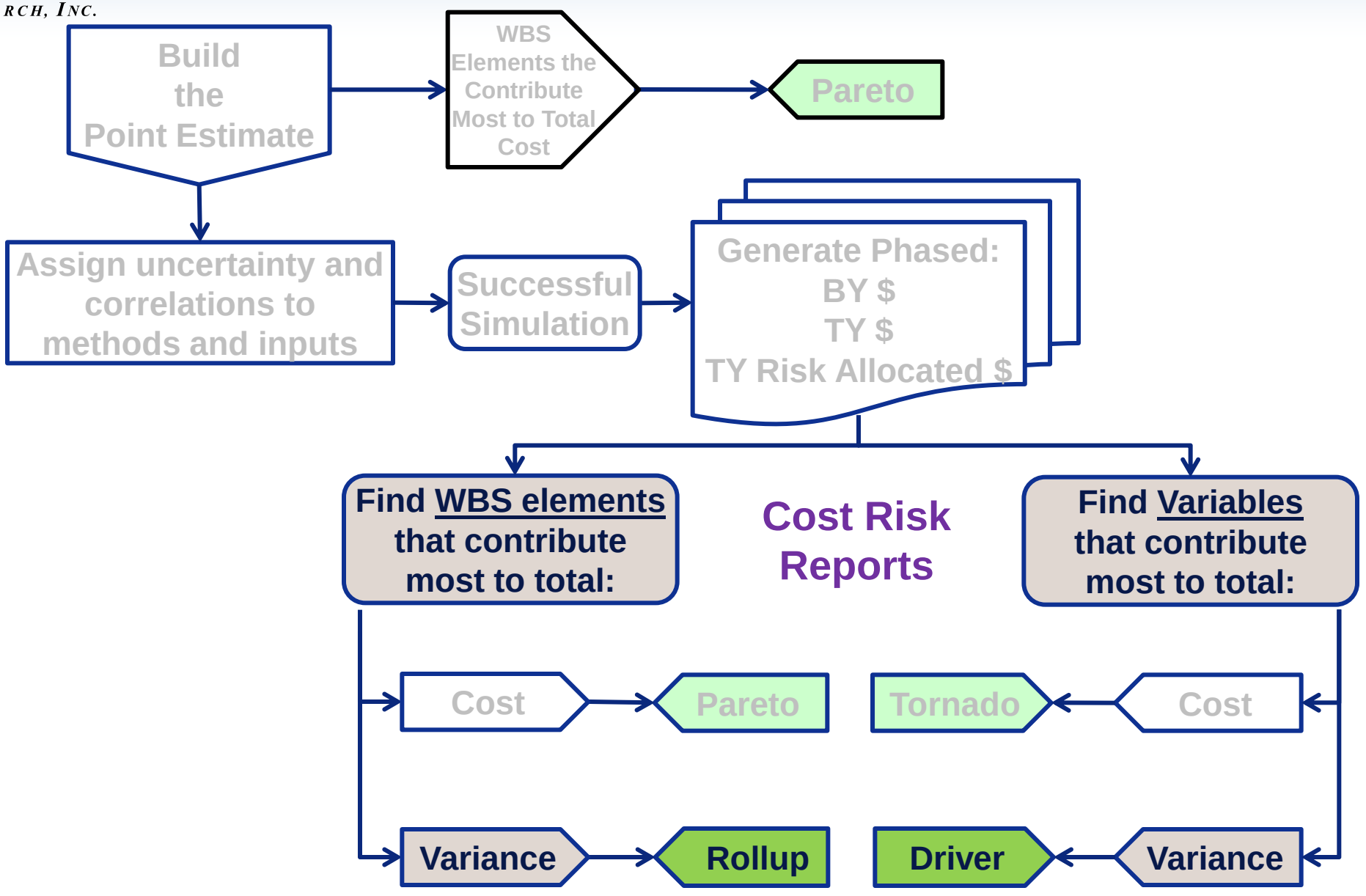
Uncertainty Driver Reports



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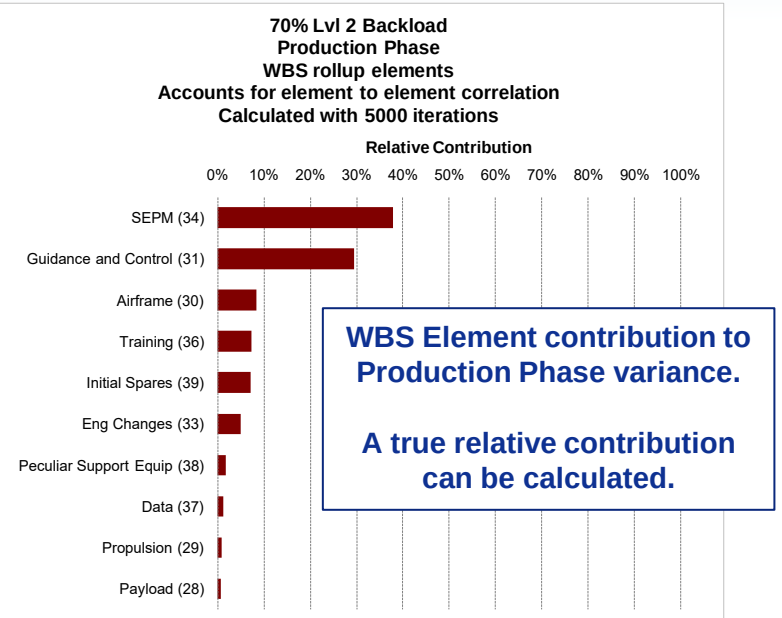
Find the Uncertainty Drivers

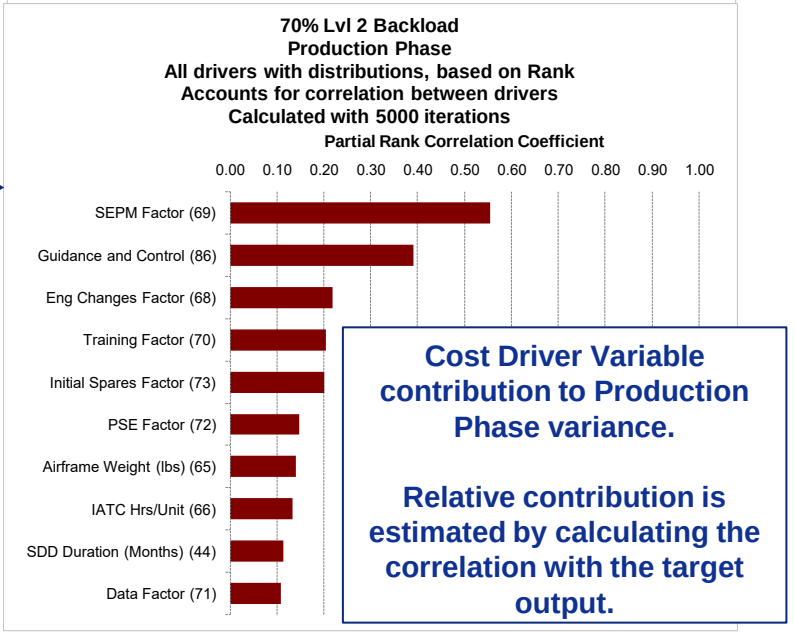
- **Variance Analysis (Rollup):** identifies WBS elements that contribute most to the target row *uncertainty*
  - Closed form analytic solution

$$\text{Total Cost Variance} = \sum_{k=1}^{n} \sigma_k^{\,2} + 2\sum_{k=2}^{n}\sum_{j=1}^{k-1} \rho_{jk}\sigma_j\sigma_k$$

  - Where: σ is standard deviation and ρ is correlation
    (when all ρ=0, becomes simple sum of variances)



- **Variance Analysis (Driver):** identifies the distributions defined anywhere in the model that contribute most to the target row *uncertainty*
  - derived by comparing rank correlation of input distributions to target output



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Find the Key Contributors to Total Uncertainty

- **Uncertainty distributions are assigned to:**
  - cost method uncertainty
  - cost method inputs
- **The objective of a "Variance Analysis" is to find the most important contributors to the Total uncertainty**
- **Should examine different types:**
  - **WBS Rollup**: Find WBS elements that contribute the most to total uncertainty (cost passengers)
  - **All Drivers**: Find distributions anywhere in the model (methods or inputs) that contribute the most to total uncertainty
  - **Some Drivers**: Consider a specific subset of distributions in the model
    - For instance, examine only those distributions assigned to input variables (cost drivers)
    - Similar to a Tornado analysis targeting input variables (thus can be a source of further confusion)

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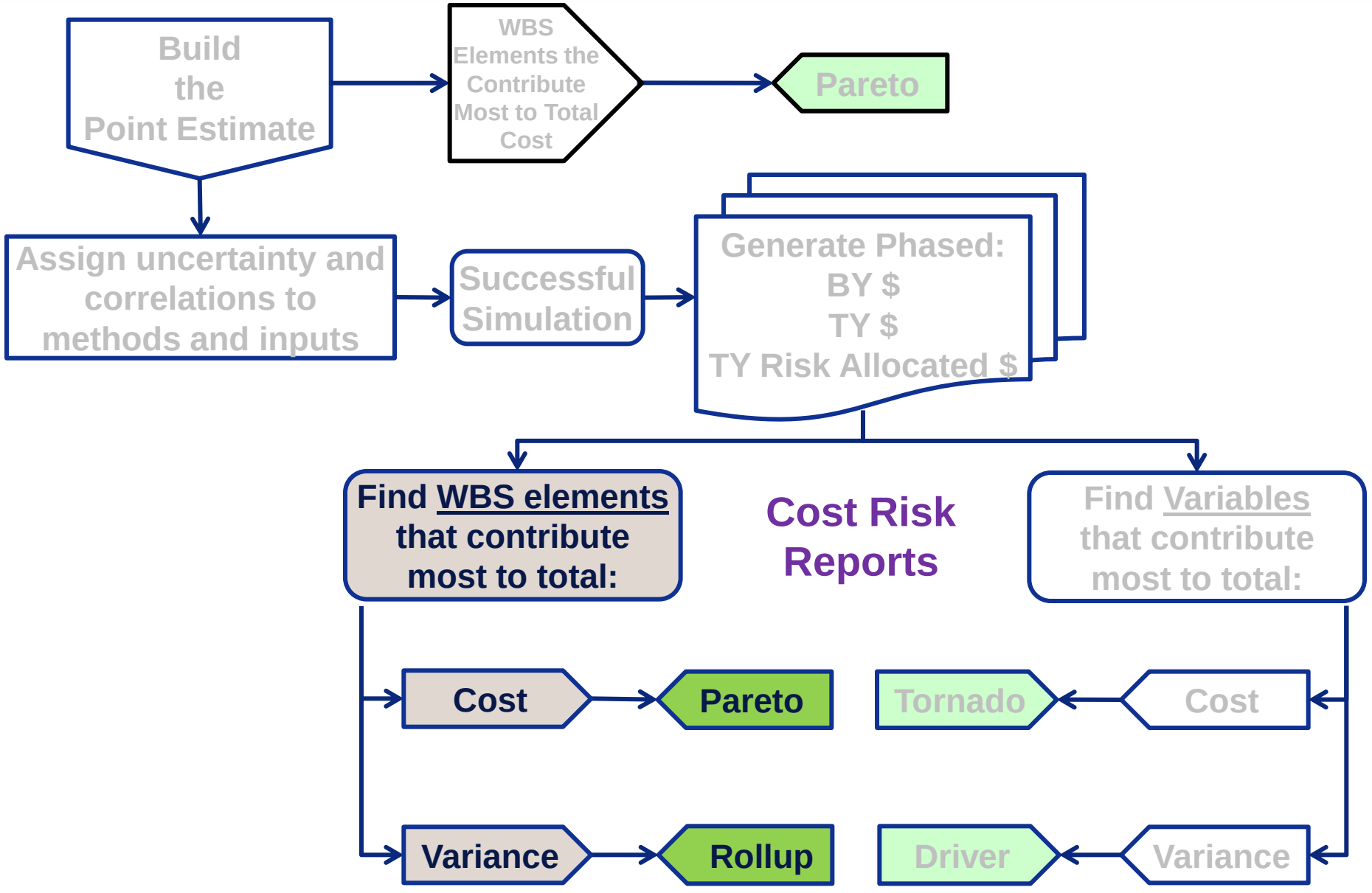
WBS Elements that Contribute Most to Total Uncertainty



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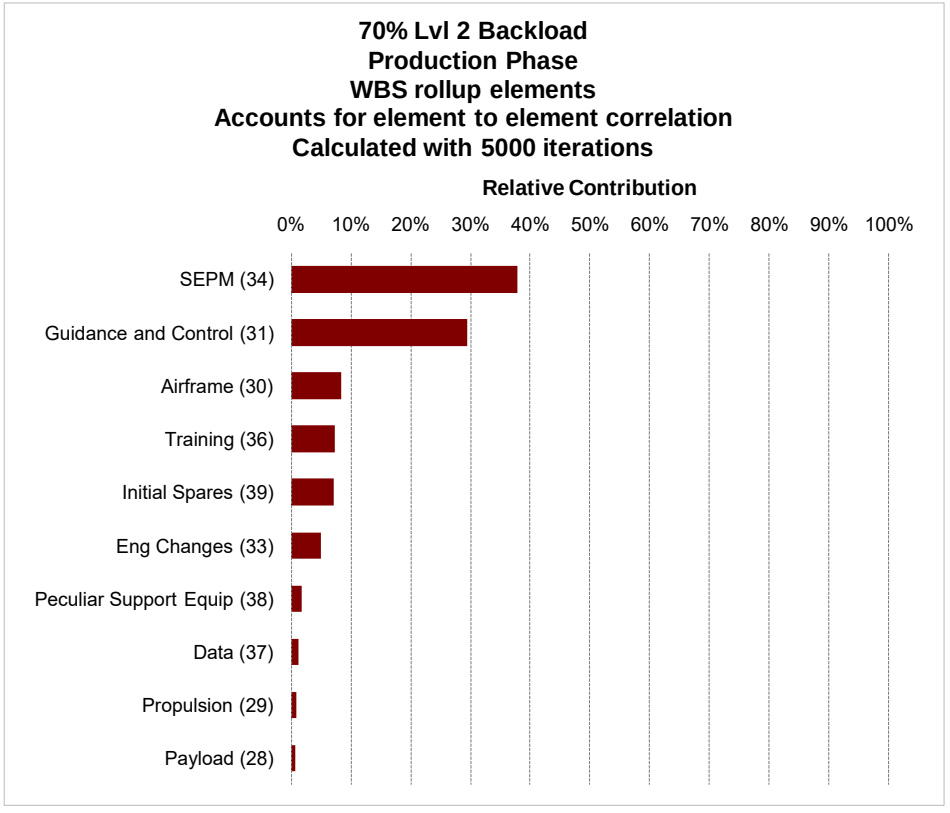
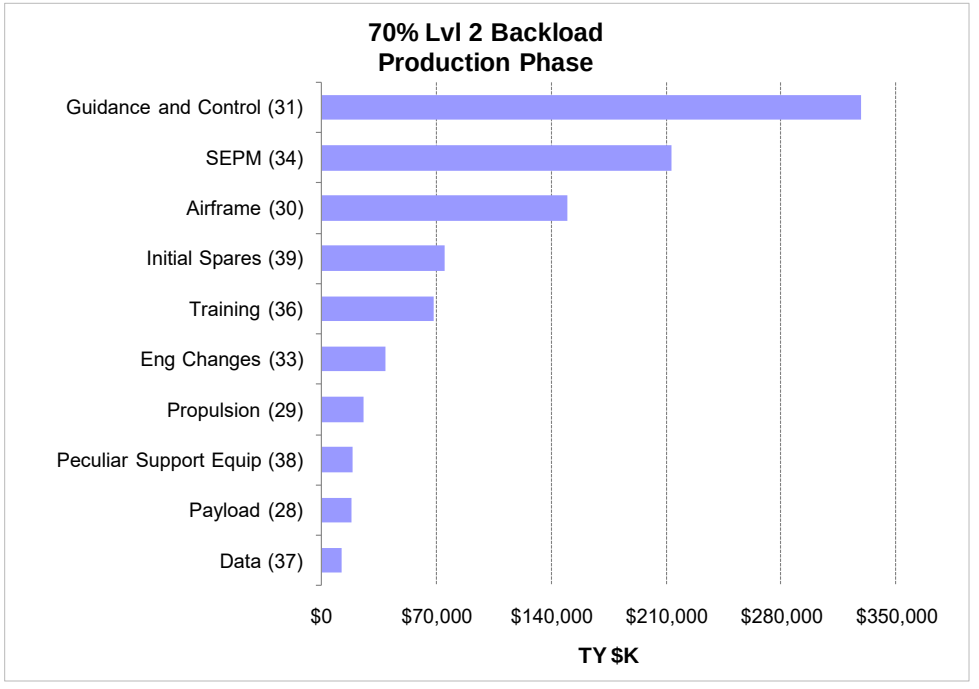
Compare WBS Rollup Variance Analysis with Pareto





- WBS Rollup (left) is not in same order as the Pareto (right)
- Can we make sense of this? Should there be a relationship?

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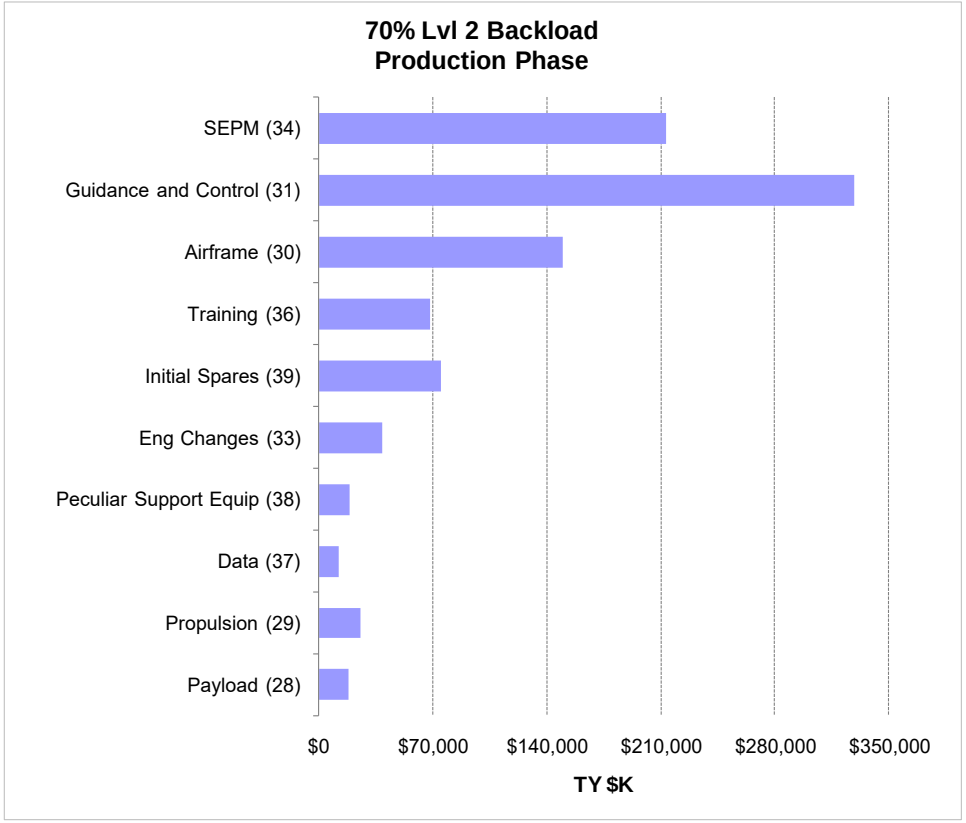
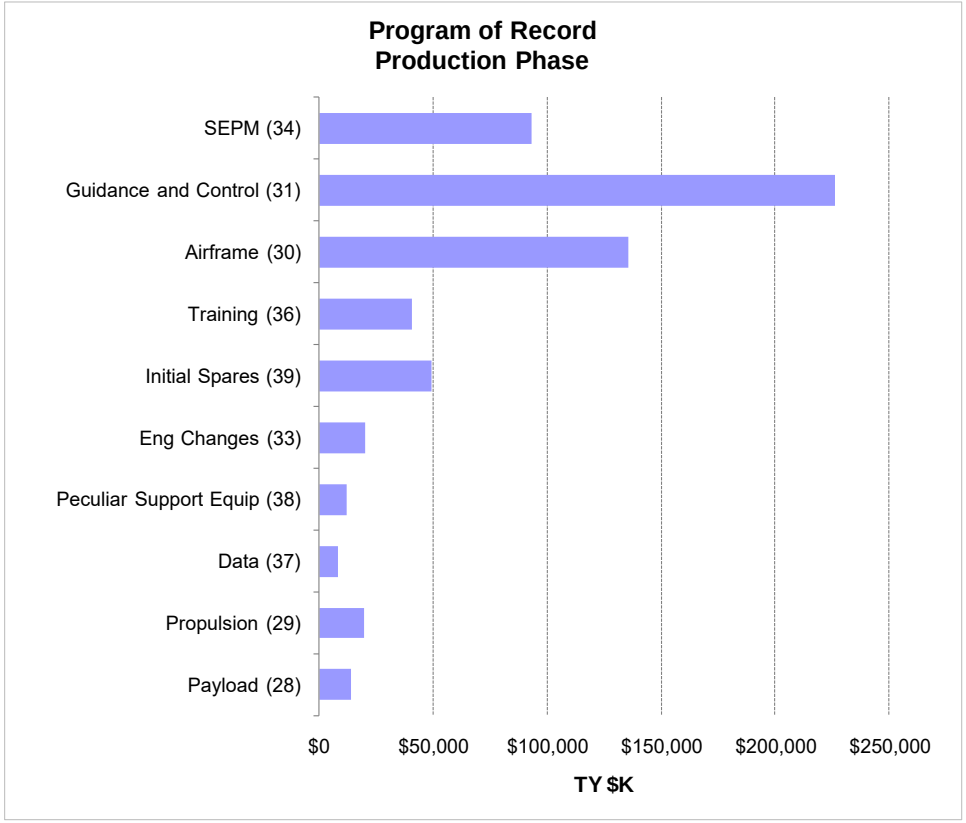
Use Pareto Reports to Derive Risk Dollars by Element





- Create a Pareto Risk Allocated (left) and Point Estimate (right), both in TY$
- Sort elements to same order as Rollup Variance chart to facilitate comparison
- Left-Right = Risk $, use this to create a Pareto based upon % contribution

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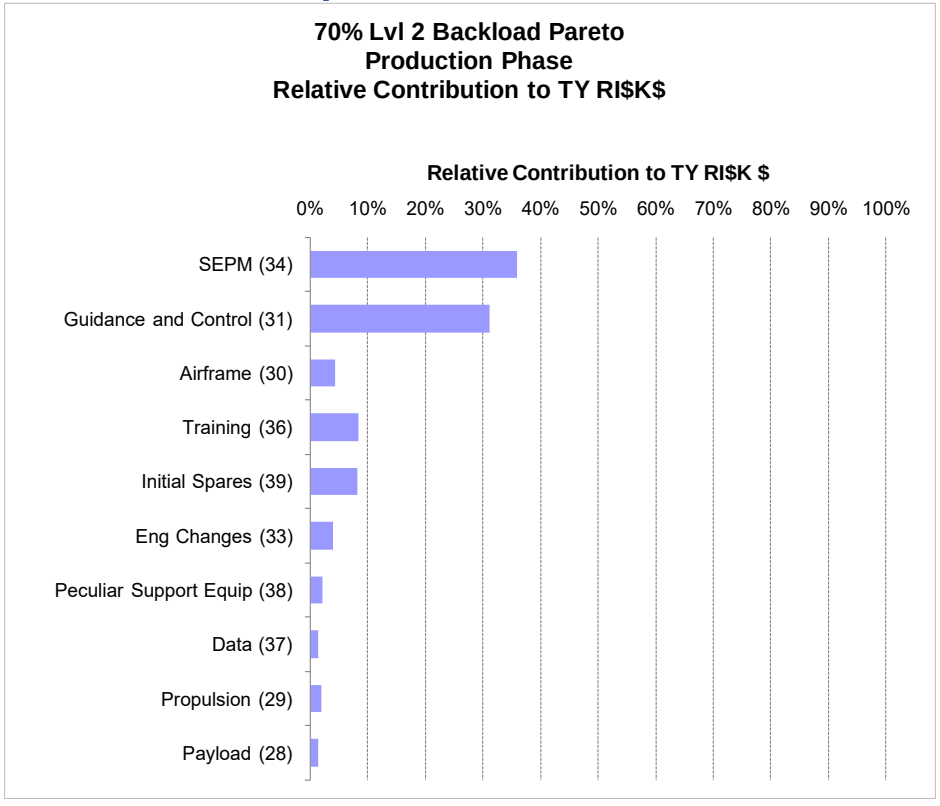
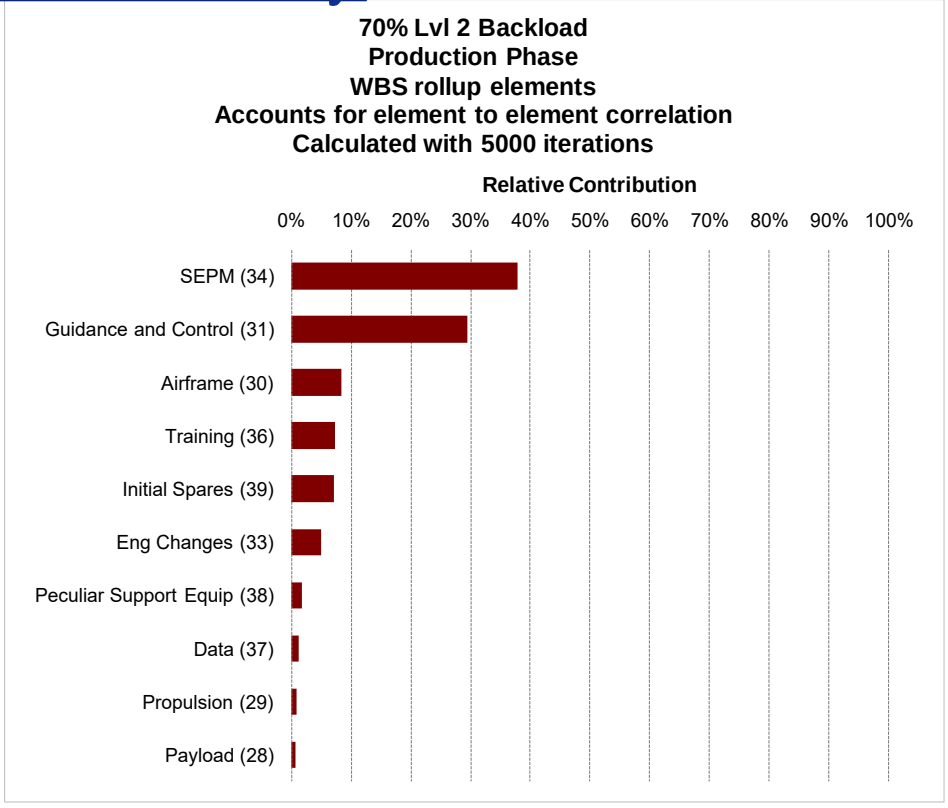
Compare Rollup Variance to Pareto Based on Relative Contribution to Risk $

Easier to Explain | Both Tell The Same Story | Easier to Perform





- General agreement; anomalies are likely due to allocation process
- Rollup Variance Analysis identifies WBS elements that contribute most to Risk Dollars

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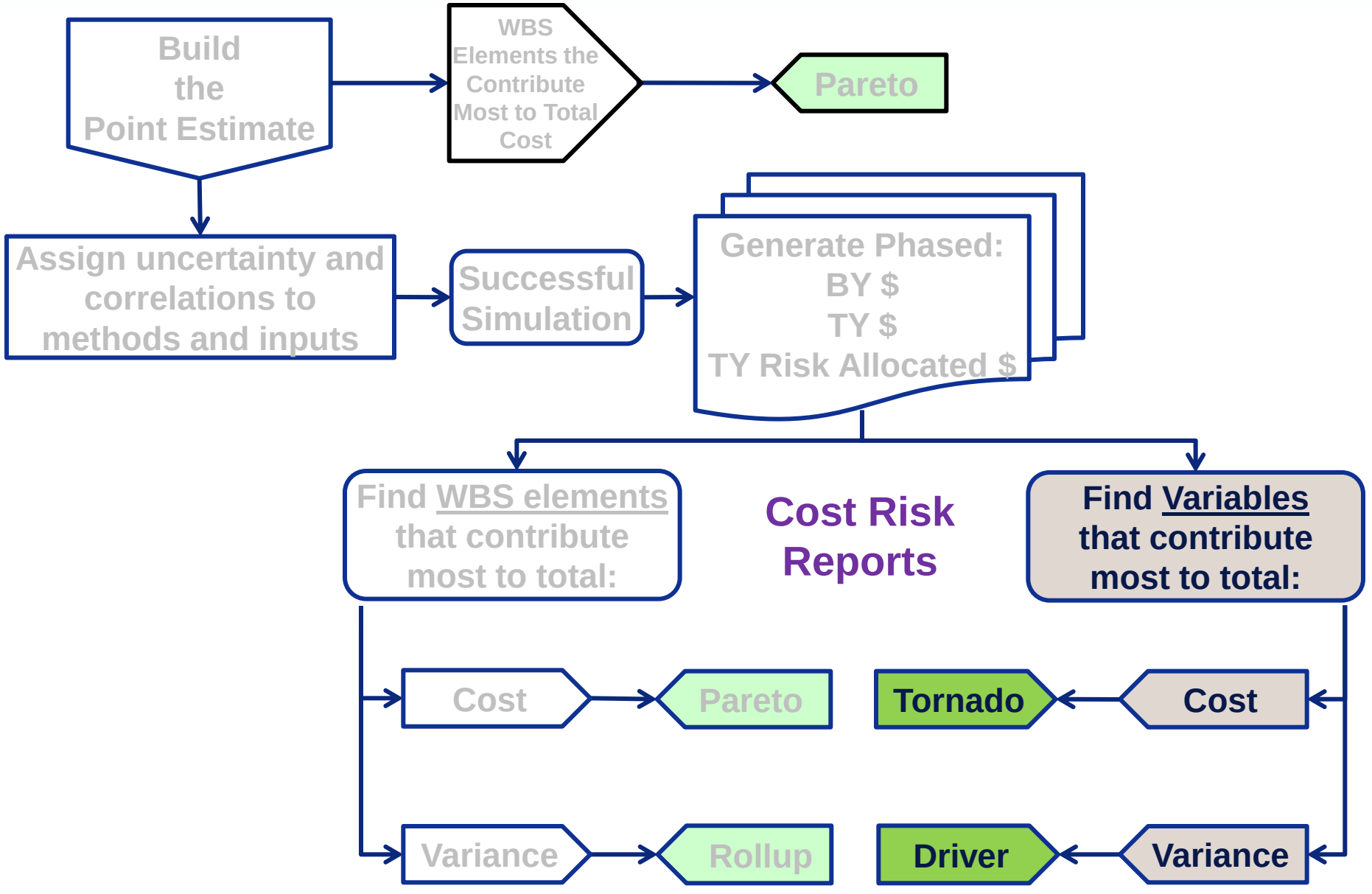
Variable Influence on Cost and Uncertainty



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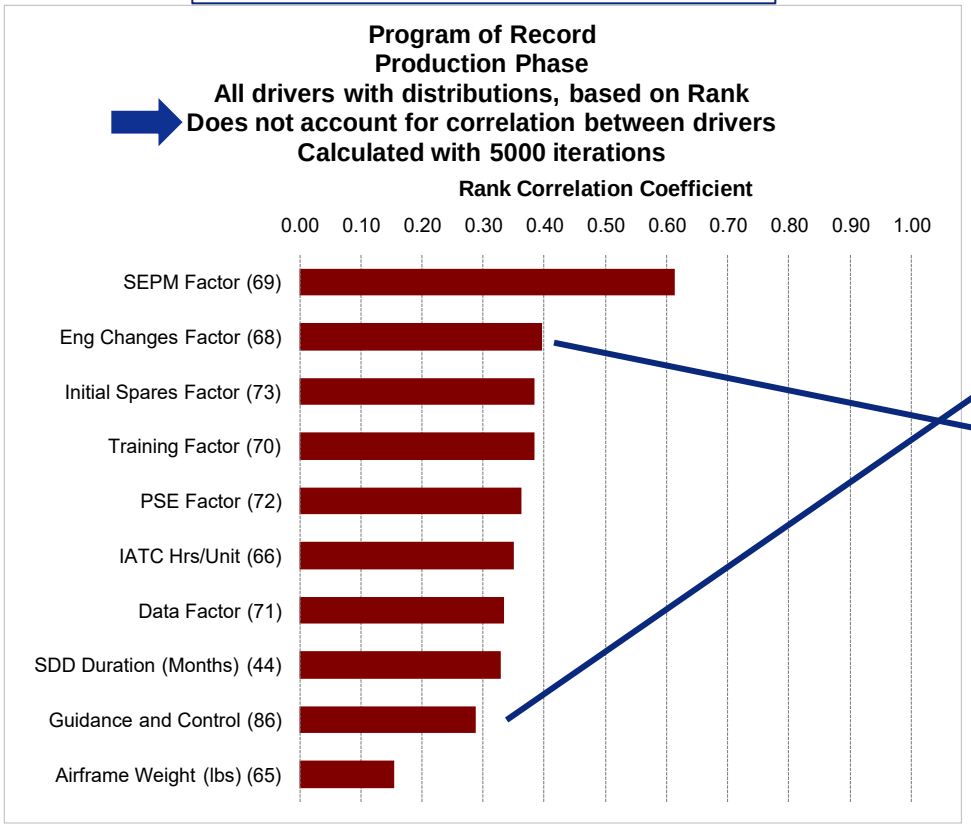
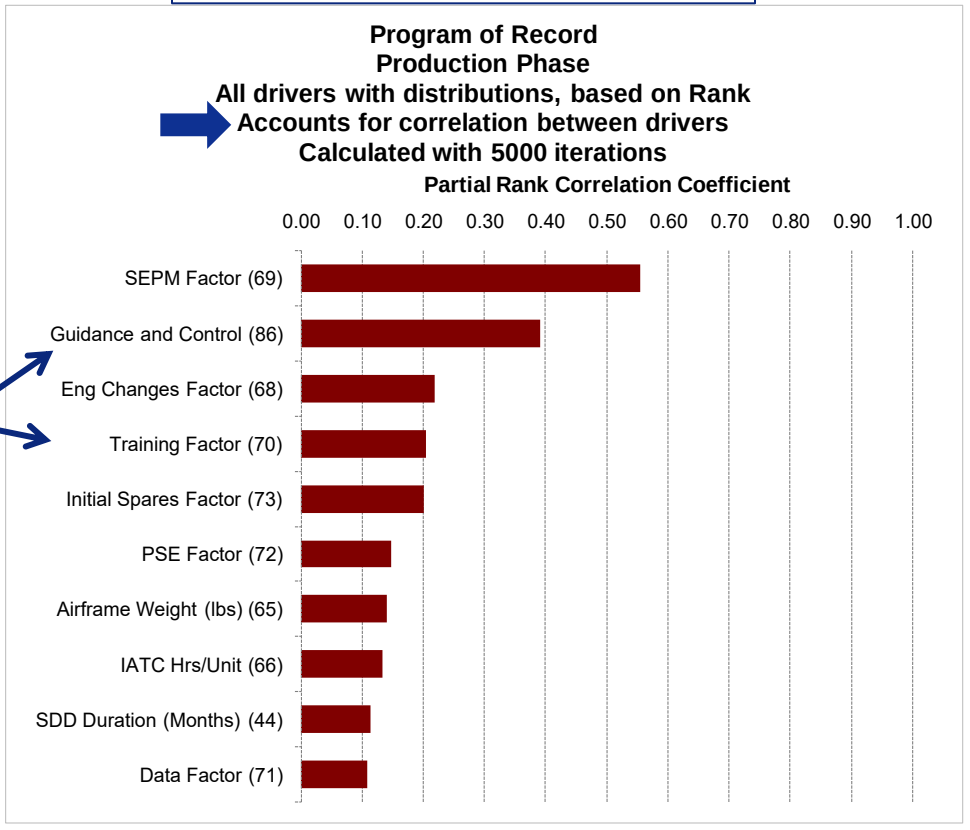
Variance Analysis: Identify Drivers That Contribute Most to Total Uncertainty

Not Recommended



Recommended



- **Variance Analysis NOT accounting for correlation**
- **Variance analysis always performed on BY results (there is no choice)**

- **Account for correlation[1] between elements**
- **Note the significant changes to the results**

[1]Mishra, S., "Sensitivity Analysis with Correlated Inputs - An Environmental Risk Assessment Example", *1st Crystal Ball User Conference*, Denver, CO, 17-18 June 2004.

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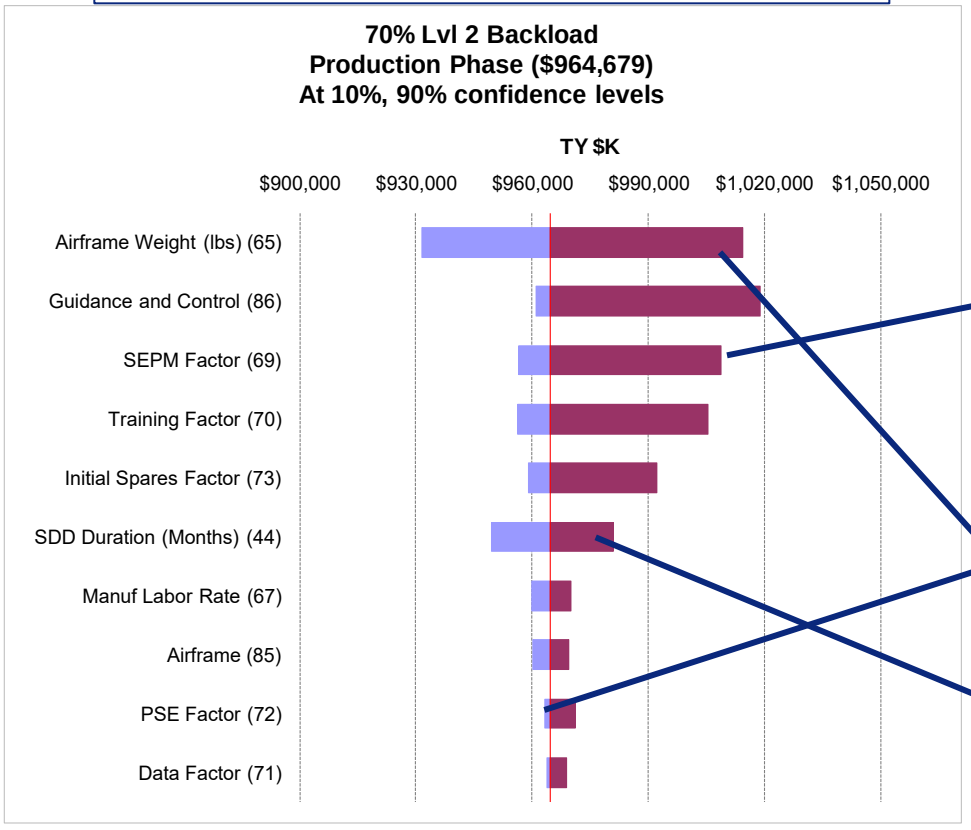
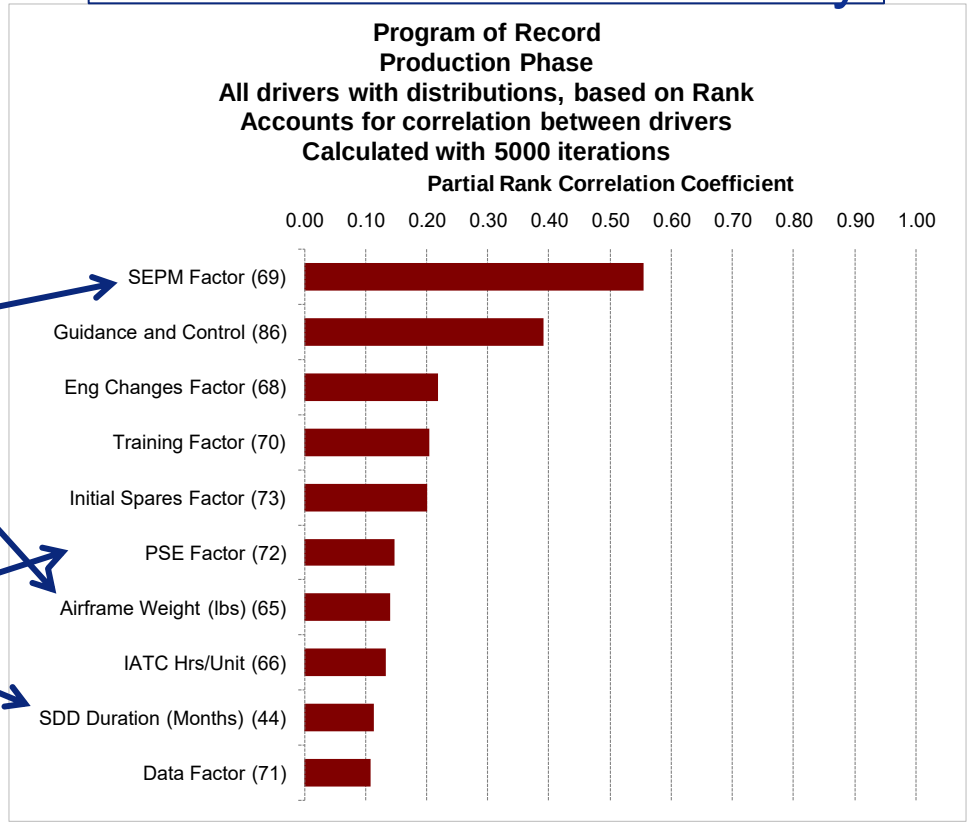
Influence on Cost is Not the Same as Influence on Uncertainty

Influence Total Cost



Influence Total Uncertainty



- **Tornado identifies variables that most influence Total Cost**
  - Performed on the Risk Allocated case
- **Variance Analysis identifies variables that most influence Total Uncertainty**
  - Performed on any case

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Summary

- **Use TY Risk Allocated case when creating**
  - **Pareto**:
    - Find the WBS elements (cost passengers) that drive **total cost**
    - Can be used to identify top contributors to Risk Dollars
  - **Tornado**:
    - Find the variables (cost drivers) that drive **total cost**
    - Examine 10/90 uncertainty bounds on potential cost drivers
- **Use any case when creating**
  - **Variance Analysis Rollup**:
    - Find WBS elements (cost passengers) that drive **total uncertainty**
    - Results are sorted based on variance, accounting for correlation
  - **Variance Analysis Non-rollup** :
    - Find variables (cost drivers) that drive **total uncertainty**
    - Results are sorted based on rank correlation, accounting for correlation

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Backup Slides

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A Word of Caution on Tornado Charts

- **Assessing extreme bounds (10/90%) can lead to very extreme results depending on modeling methods**
  - Useful for identifying which variables have the potential to be most harmful
  - Fixed +/- 5% can give PM guidance on what elements have the biggest impact for a small change, that is give him/her goals he/she can achieve
- **Be wary of "Fixed range" testing. Every driver, even those that are not uncertain (e.g., a units conversion) will be tested unless the user excludes them**
- **Tornado charts assess one variable at a time**
  - Can underestimate the true impact if other variables should move with the tested one
  - Building functional relationships between variables will address this problem
  - If specific combinations of variables are of interest, they should be examined as specific what-if cases

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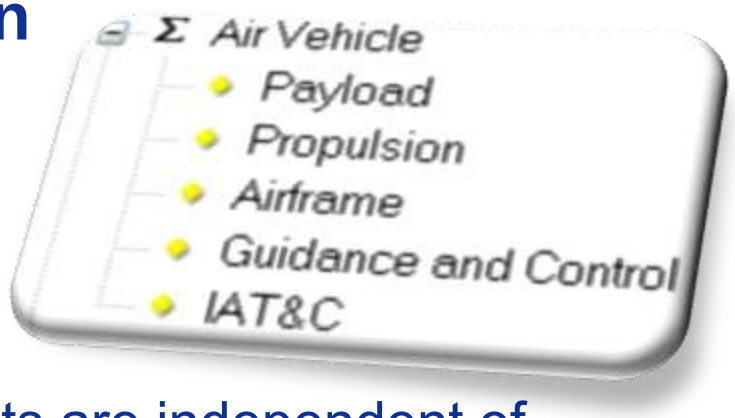
How Does RollUp Variance Analysis Work?

- **Two statistics sum in a simulation**
  - Mean
  - Variance



- **Total Variance** $= \sum_{k=1}^{n} \sigma_k^{\,2}$
  - Above formula only true if child elements are independent of each other (σ = standard deviation)
- **Total Variance** $= \sum_{k=1}^{n} \sigma_k^{\,2} + 2\sum_{k=2}^{n}\sum_{j=1}^{k-1} \rho_{jk}\sigma_j\sigma_k$
  - This formula accounts for correlation (ρ)
  - Reduces to first formula if all correlations are 0
- **POST measures the correlations first then uses the second formula to estimate the correlation adjusted variance for each child element**

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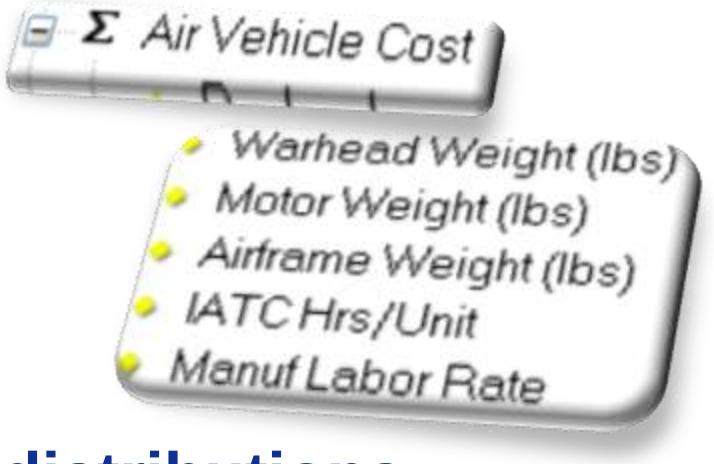
How Does Driver Variance Analysis Work?

- **How does one measure the contribution of different input types (wgt, factors, rates, etc) on total cost variance?**
- **Solution: measure correlation**
  - Compare input distributions to target output distribution
  - Default is rank correlation by every tool



- **If correlations are applied to input distributions, most tools report that "results will be misleading"**
  - The message is almost always ignored
- **POST can account for applied correlation!**
  - the input with the largest partial correlation coefficient is the input with the largest contribution to total variance

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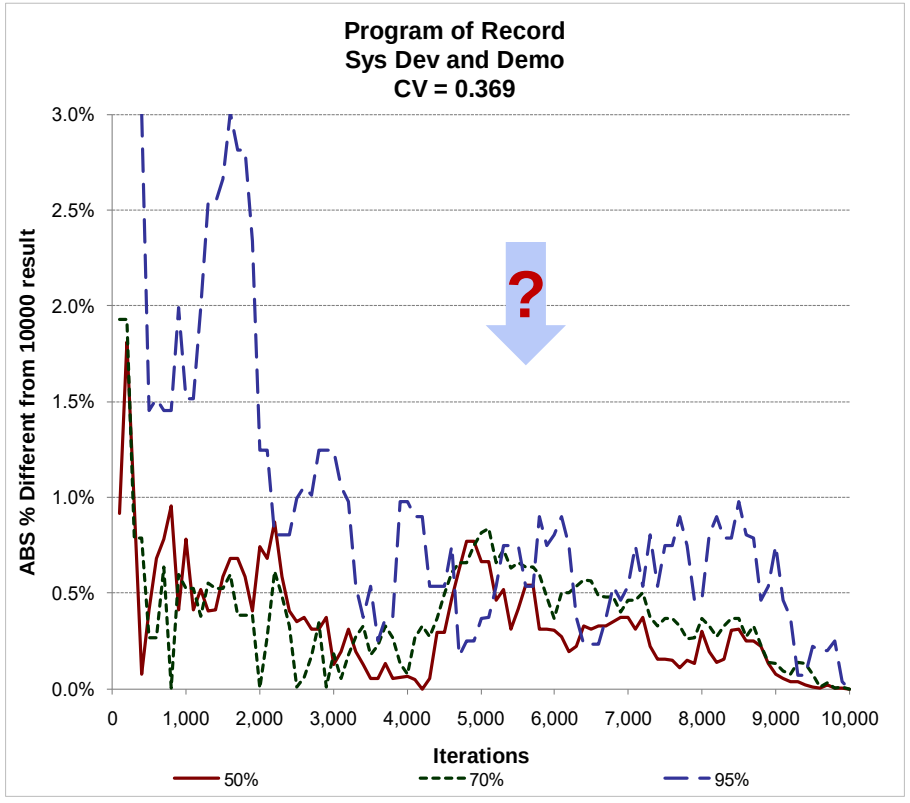
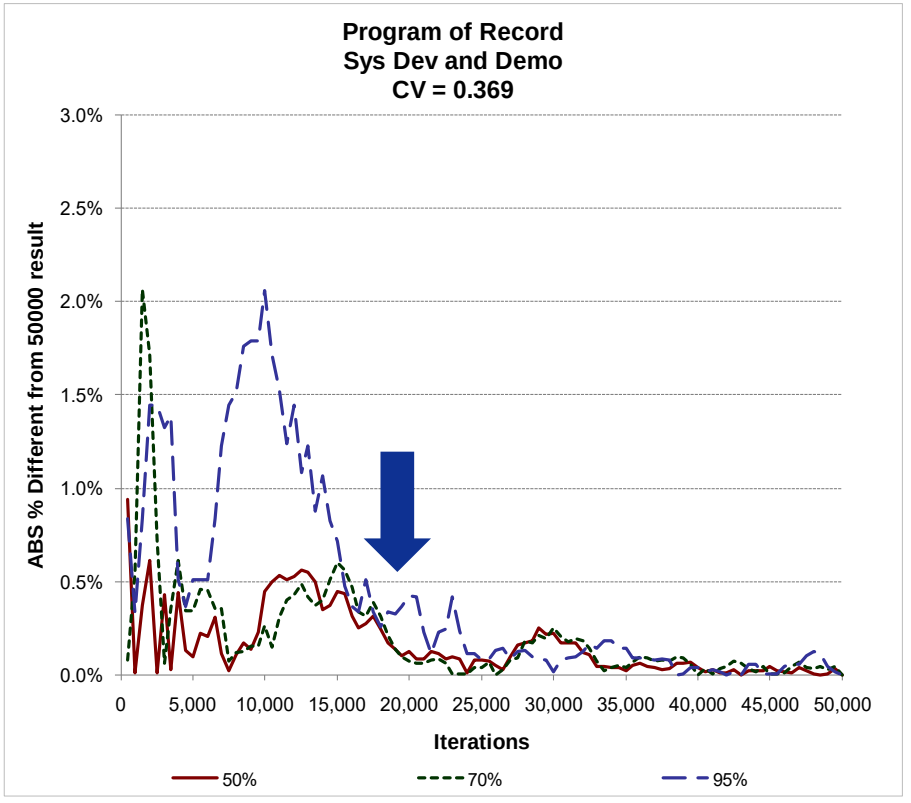
What To Do If Target Does not Converge





- POST Convergence Chart, default settings, for SDD does not demonstrate convergence
- Need to change POST Convergence report option to more iterations (50k selected)
- SDD requires 20k (maybe 25k) to converge
- Must reassess all if model changes